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A SIMPLE METHOD FOR PREDICTING SUBJECTIVE RESPONSE TO NOISE ON NAVY SHIPS

DR Lambert

15 November 1979

Prepared for
Naval Sea Systems Command

NAVAL OCEAN SYSTEMS CENTER
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A graphical method of data analysis is presented for predicting response of shipboard personnel to airborne noise when compartment type and sound level are specified. To illustrate application of the method, the author used the subjective responses of personnel to rate stateroom noise aboard eight U.S. Naval ships on a 5-point scale ranging from satisfactory to unsatisfactory. These ratings were then plotted as a function of A-weighted sound level and three parameters were estimated. Graphs for predicting subjective ratings from level were then constructed.

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FOREWORD

This document has been prepared for the Naval Sea Systems Command (NAVSEA 05H) for general guidance in development of noise standards for U.S. Navy ships. It is one of several dealing with various aspects of noise as related to habitability and the safety of personnel aboard Navy ships.

The assistance of DR Schmidt and RS Gales in reviewing the manuscript is gratefully acknowledged.

CONTENTS

INTRODUCTION

This paper presents a cost effective method for using sound pressure level and subjective rating data to evaluate airborne noise limits for shipboard compartments of similar type. Such limits are needed for the purpose of insuring that noise does not interfere with ships' missions. The present limits for several types of compartments aboard Navy ships are currently under review by the Naval Ocean Systems Center.

Applying the method presented here produces a graph showing how subjective ratings are affected by noise level. When a sound level is specified, this graph can be used to predict the percentage of compartments which will meet each subjective rating score.

This method is approximate, and is less rigorous than procedures such as calculating means and standard deviations; however, it has several significant advantages. It is extremely simple in concept and application. It is economical and can be performed easily and rapidly by hand without the aid of a computer. The resulting composite graph displays the actual available data, shows how the analyst approximated the data by two parallel lines (e.g., which points were outside the approximation), gives the percentage of compartments predicted to meet each rating, and allows one to see how much each compartment would need to be improved to meet any hypothesized noise limit. Thus, it is readily used and interpreted, even by those relatively unfamiliar with noise, and is directly and simply related to the actual data so the effect of additional new data is readily apparent. Moreover, well defined predictions of subjective response can be made even with small amounts of data until they can be improved by refining the parameter estimates as additional data become available.

In this presentation of the method, subjective ratings of whether or not the noise in a compartment is satisfactory are related to A-weighted sound level by plotting the data as a graph. The boundaries of a group of points are estimated by eye and represented by two parallel straight lines. Slope, intercept, and the distance between the two lines may then be measured and used directly to construct a graph predicting the subjective response of shipboard personnel to noise as a function of sound level.

Theory is presented in appendix D. Subjective ratings were obtained using the questionnaire in appendix A. Bounded, discrete rating scales were used to simplify the questionnaire as much as possible in order to maximize return of data in the shipboard environment. An alternative, often used under more controlled conditions, would have been to use unbounded, continuous, quantitative rating scales and fit a straight line to the data by eye or by using regression analysis. Information about the distribution of the data would then have been provided by the slope, intercept, and standard deviation of the regression line. This method would have avoided effects due to boundaries and the discrete nature of the rating scale; but it would be more laborious to perform and the results would be less convenient to interpret. Furthermore, it could give an appearance of more precision than warranted by the consistency of subjective ratings taken in the shipboard environment.

METHOD WITH EXAMPLE OF APPLICATION

STEP 1. Measure sound level in each compartment. A-weighted sound levels were measured in staterooms aboard eight Navy ships underway at normal cruising speed. Levels were usually steady.

In this report, sound level denotes A-weighted sound level unless otherwise modified. This analysis procedure may also be used with other measures such as octave band level or C-weighted sound level.

STEP 2. Obtain, from personnel in each compartment, subjective ratings of the effects of the noise on them. Subjective ratings were obtained by using survey data sheets (appendix A) which were filled-in by personnel who regularly used each stateroom. Among others, ratings of interference with communication, work, and sleep were included.

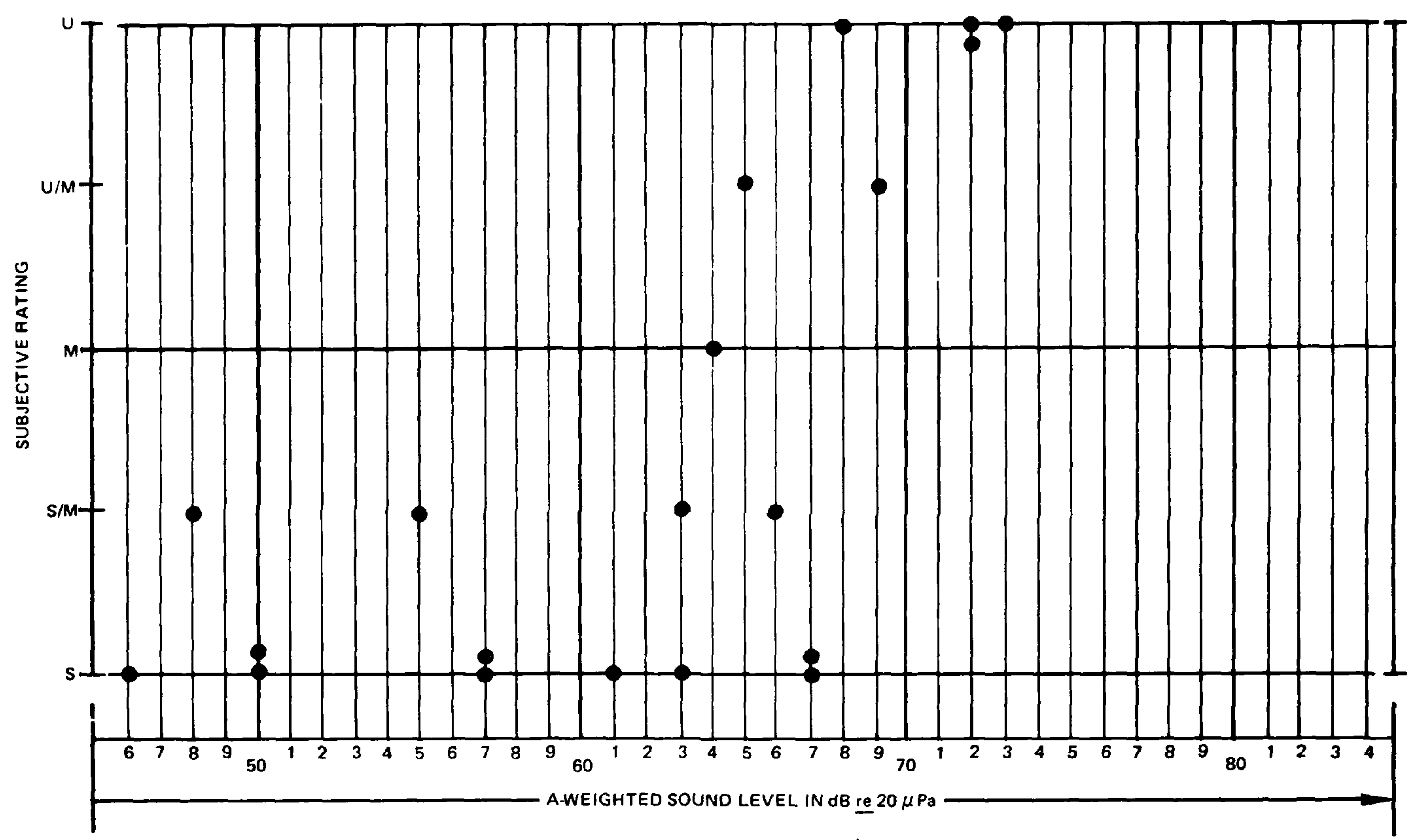
Care is needed to insure that the subjective ratings reflect the noise actually measured, especially if transient noises are involved. And, when a compartment is used for multiple activities, it is helpful to specifically determine which activities are being reflected in the rating because their susceptibility to interference differs.

STEP 3. Determine from the subjective ratings a single number for each compartment which represents the effect of the measured noise. For this example, the author used a rather loosely defined composite rating, involving both the opinions of the occupants and the author's subjective judgements (appendix B). The relevant data from all of the pertinent survey information were used to rate each compartment subjectively on a 5-point scale: satisfactory (S), marginally satisfactory (S/M), marginal (M), marginally unsatisfactory (U/M), and unsatisfactory (U). This analysis procedure may also be used with other subjective measures.

STEP 4. Plot the data for each compartment to produce a graph of subjective rating vs. sound level. The subjective ratings for staterooms aboard eight U.S. Navy ships were plotted as a function of A-weighted sound level (figure 1) using a copy of the sample graph paper provided in appendix C. At sound levels at or below 62 dB(A), nearly all of the spaces are rated as satisfactory. At levels at or above 70 dB(A), all are unsatisfactory. In between, there is a transition zone in which the ratings shift from satisfactory to unsatisfactory as sound level increases.

STEP 5. Estimate three parameters from the graph: rating scale intercept, transition zone width, and slope. We can approximate the boundaries of the transition zone by two parallel straight lines (figure 2). To improve the consistency of transition zone boundaries fitted by eye by different analysts, the following conventions should be observed:

(1) Use the narrowest, steepest pair of parallel straight lines which seem to fit the data, rather than a wider pair with a lower slope. In doing this, it is permissible to ignore up to about 10 percent of the points, especially those obviously outside the distribution pattern. Also, completely ignore those points not necessarily within the transition zone as stated in (2) and (3) below.



U	UNSATISFACTORY
U/M	MARGINALLY UNSATISFACTORY
M	MARGINAL
S/M	MARGINALLY SATISFACTORY
S	SATISFACTORY

Figure 1. Subjective ratings of noise in staterooms as a function of A-weighted sound level. Data from eight Navy ships.

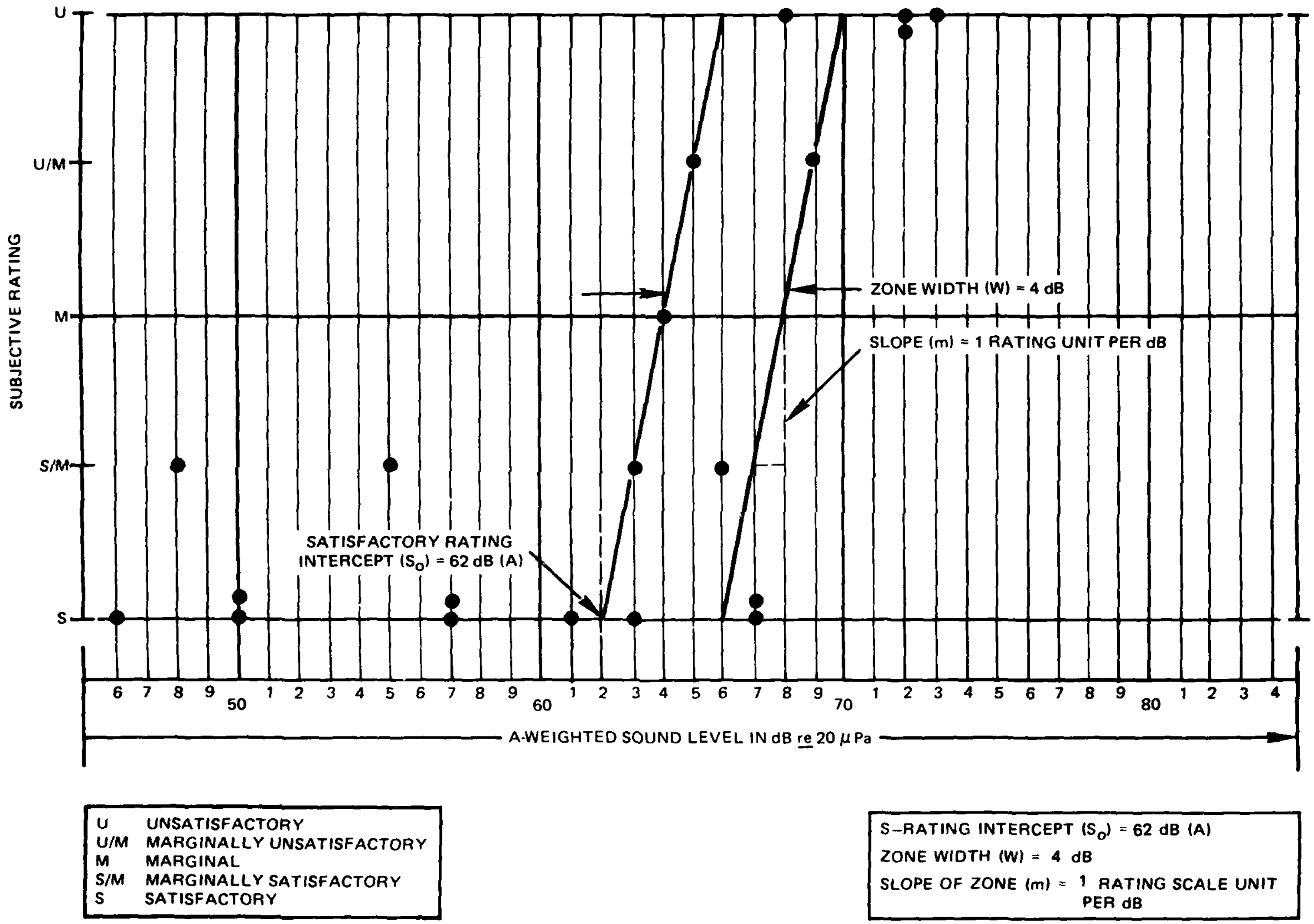


Figure 2. Subjective ratings of noise in stateroom compartments as a function of A-weighted sound level. Data from eight Navy ships.

(2) In determining the right-hand boundary of the zone, heavily weight those points rated S which have the highest sound levels. Completely ignore all points rated U, since these points are not necessarily within the transition zone.

(3) In determining the left-hand boundary of the zone, heavily weight those points rated U which have the lowest sound levels. Completely ignore all points rated S, since these points are not necessarily within the transition zone.

In figure 2, the zone's lower boundary intercepts a rating of satisfactory at 62 dB(A). This sound level is S_0. For sound levels not exceeding S_0, nearly all of the staterooms received a satisfactory rating. The width (w) of the zone is 4 dB, and its slope (m) is one rating scale division per dB. All spaces with measured sound levels at or above 70 dB(A) received an unsatisfactory rating. Thus, the subjective rating intercept (S_0), zone width (w), and slope (m) are quickly estimated by inspection.

STEP 6. Use these three parameters to plot predicted subjective rating as a function of sound level. Such a graph may be constructed very easily from the three paramaters S_0, w, and m by using the computation worksheet and sample graph paper in appendix C to work through the procedure below. This has been done for this example in table 1 and figure 3.

(a) Record measured values of S_0, w, and m on the computation worksheet (table 1). Mark the horizontal axis of the graph at S_0 (figure 3).

(b) Compute 1/m = 1/1 = 1.

(c) Compute w_d = 1/m - 1 = 1 - 1 = 0 dB. Compute (S_0+ w_d) = (62 + 0) = 62 dB(A). Draw a vertical line through the horizontal (sound level) axis at (S_0+ w_d).

(d) Since w = w_d + w_v (appendix D), we may compute w_v = w - w_d = 4 - 0 = 4; and n (defined in appendix D) = w_v + 1 = 5.

(e) Compute (S_0 + w + 1) = (62 + 4 + 1) = 67 dB(A). Connect points (S_0+ w_d, 100%) and (S_0 + w + 1, 0%) with a straight line. This line, labeled S, is the satisfactory rating line.

(f) Draw three more lines parallel to the satisfactory rating line at intervals of 1/m dB. These are the S/M, M, and U/M lines. Note that each subjective rating line drops from 100% to 0% in w_v + 1 dB. The distance between lines is equal to 1/m; i.e., equal to the change in sound level required to cause a one-point shift in rating. The U line, not shown, always has a value of 100% since, by definition, all spaces are always unsatisfactory or better.

Table 1. Computation worksheet for figure 3.

Satisfactory rating intercept (estimated) = S_o = 62 dB(A)

Zone width (estimated) = w = 4 dB

Slope (estimated) = m = 1 rating units/dB

$1/m$ = 1 dB/rating unit

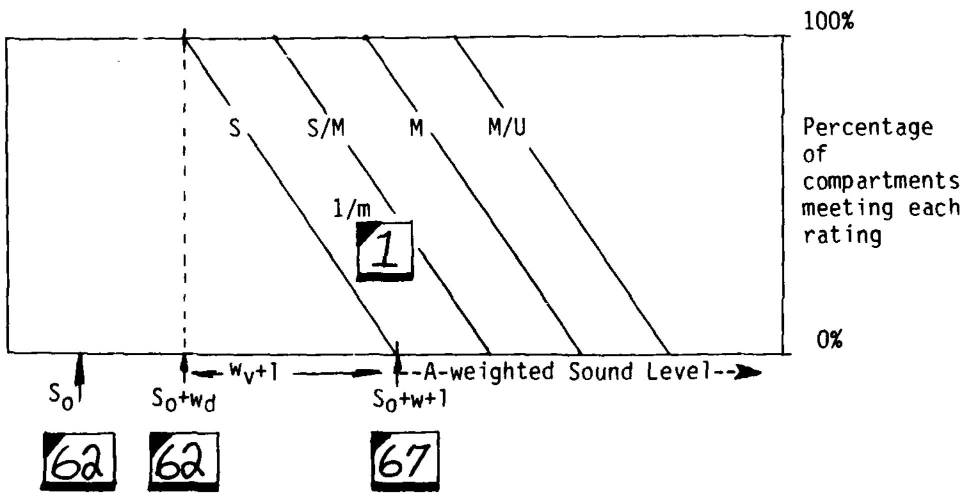
w due to discrete scale = $1/m - 1$ = (1 - 1) = w_d = 0 dB

62 + 0 = $S_o + w_d$ = 62 dB(A)

w due to variability = $w - w_d$ = (4 - 0) = w_v = 4 dB

$n = w_v + 1 =$ 5

62 + 4 + 1 = $S_o + w + 1$ = 67 dB(A)



Notes: Zone width (w) = width due to slope + width due to variability
$= w_d + w_v = (1/m - 1) + (n - 1)$
$= 1/m + n - 2$

$$S_o + w + 1 = (S_o + w_d) + (w_v + 1) = S_o + 1/m + n - 1$$

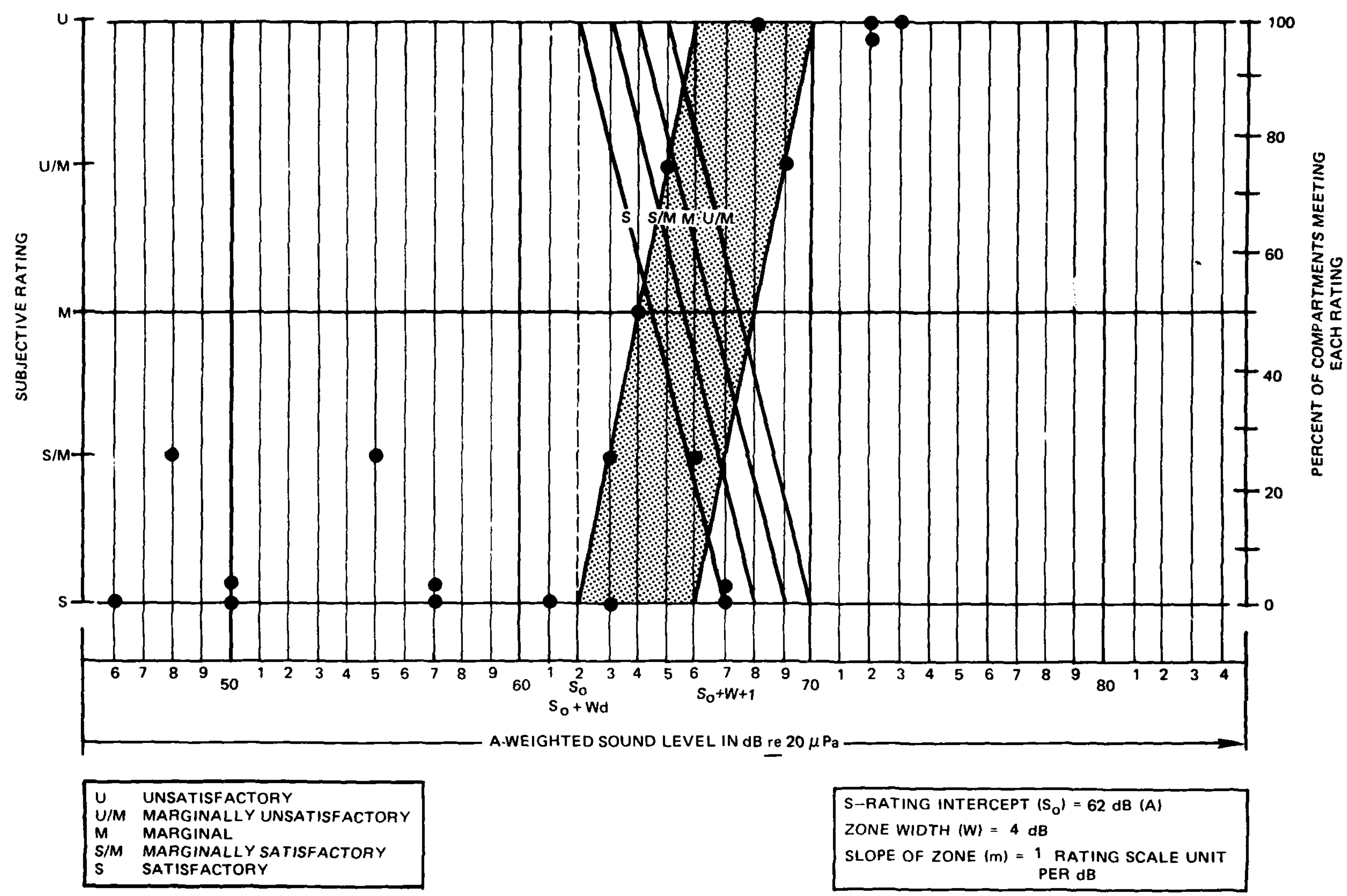


Figure 3. Subjective ratings of noise in staterooms (left axis) and percent of those compartments meeting each rating (right axis) as a function of A-weighted sound level. Data from eight U.S. Navy ships.

RESULTS AND DISCUSSION

When a sound level is specified, figure 3 can be used to predict the percentage of compartments which will meet each subjective rating score. For example, if all future staterooms were 66 dB(A), one would expect a survey to reveal about 20 percent of the spaces rated as satisfactory, 40 percent as marginally satisfactory or better, 60 percent as marginal or better, and 80 percent as marginally unsatisfactory or better. So, 20 percent of the spaces would be rated as unsatisfactory.

This kind of a graph can also be used to estimate the effect of specifying a different sound level. For example, figure 3 predicts that if the level were lowered by 3 dB to 63 dB(A), essentially 100 percent of the spaces would be rated as marginally satisfactory or better.

An analysis of data from large berthing compartments is presented in table 2 and figure 4. Here, there is much greater variability, reflected in the zone width of 11 dB; and a much greater reduction in sound level is required to produce a given improvement in subjective rating.

CONCLUSIONS AND RECOMMENDATIONS

The method of graphic analysis discussed here appears useful for interpreting data when subjective noise ratings are employed to provide information about the effects of noise on personnel. It is very simple in concept and application. Further evaluation of the adequacy of the method for describing real data in a useful way is recommended following additional experience with it.

RELATED DOCUMENTS

The following documents also apply to airborne noise on Navy ships.

NOSC TD 267, Behavioral and Physiological Effects of Noise on People: a review of the literature, by DR Lambert and FS Hafner, 30 April 1979.

NOSC TD 243, Airborne Noise Levels on Merchant Ships, by DR Lambert, 30 April 1979.

NOSC TD 317, Airborne Noise Levels on Navy Ships, by DR Lambert, in preparation.

NOSC TD ___, Airborne Noise Limits for Navy Ships, by DR Lambert, in preparation.

Behavioral and Physiological Effects of Noise on People--Supplementary Bibliography, an unpublished paper by DR Lambert and FS Hafner, NOSC Code 5121, January 1979.

Table 2. Computation worksheet for figure 4.

Satisfactory rating intercept (estimated) = S_o = 56 dB(A)

Zone width (estimated) = w = 11 dB

Slope (estimated) = m = 1 rating units/dB

$1/m$ = 1 dB/rating unit

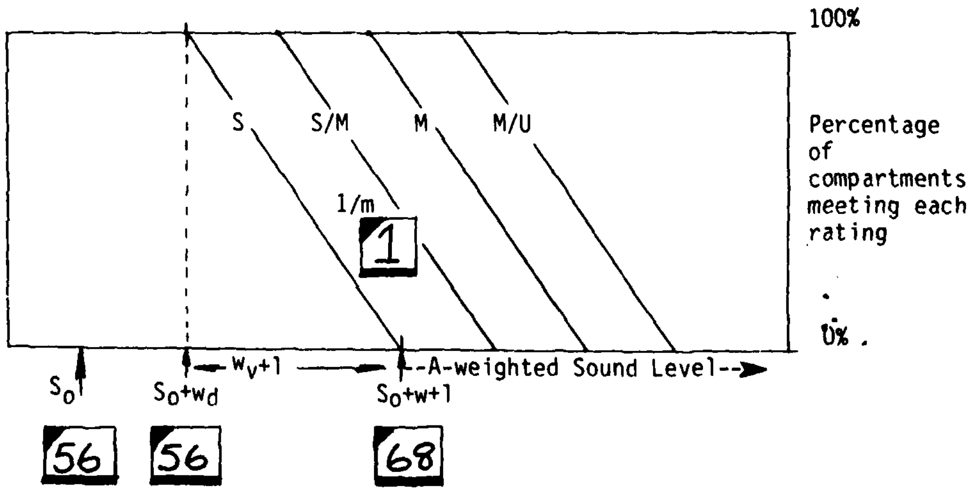
w due to discrete scale = $1/m - 1$ = (1 - 1) = w_d = 0 dB

56 + 0 = $S_o + w_d$ = 56 dB(A)

w due to variability = $w - w_d$ = (11 - 0) = w_v = 11 dB

$n = w_v + 1 =$ 12

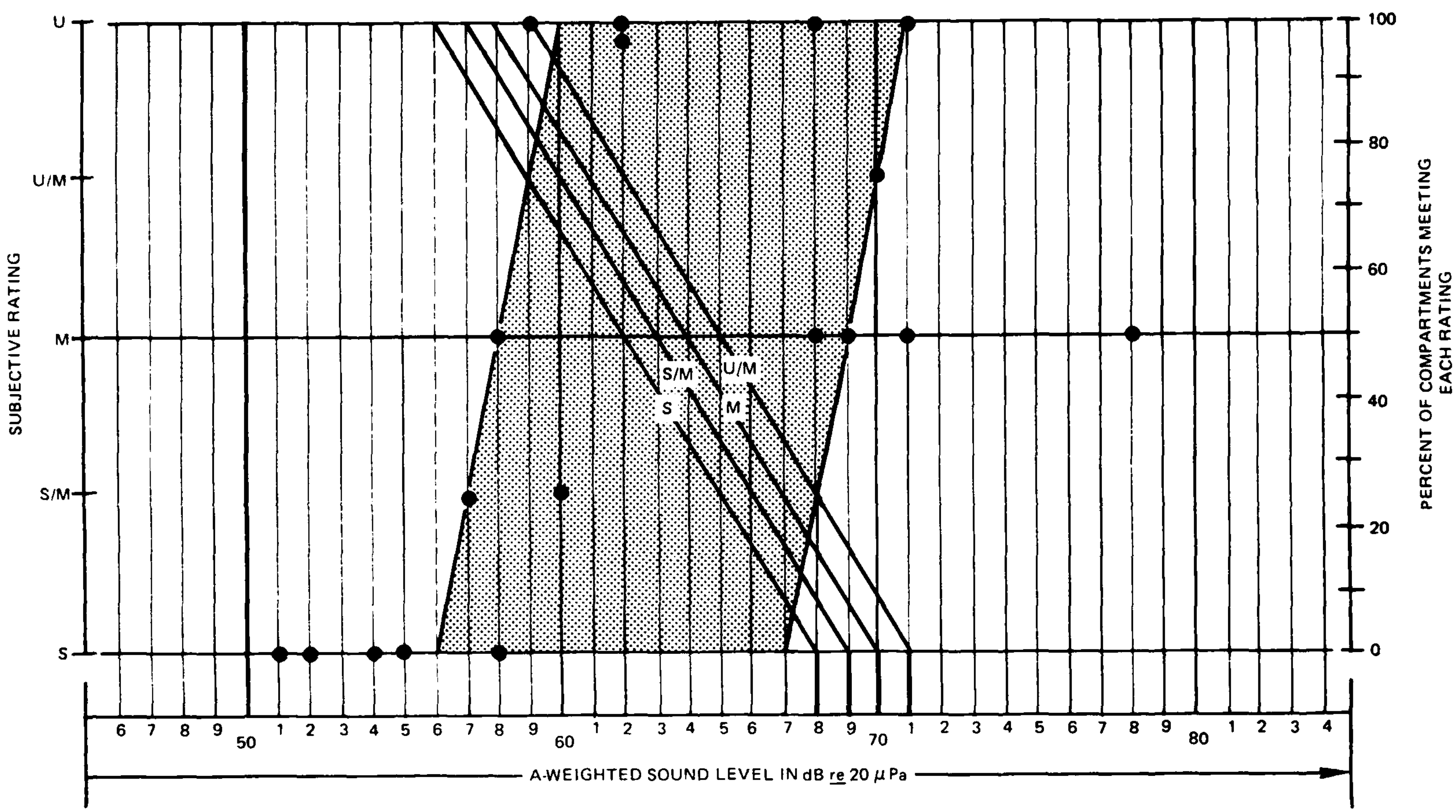
56 + 11 + 1 = $S_o + w + 1$ = 68 dB(A)



Notes: Zone width (w) = width due to slope + width due to variability

$$= w_d + w_v = (1/m - 1) + (n - 1)$$
$$= 1/m + n - 2$$

$$S_o + w + 1 = (S_o + w_d) + (w_v + 1) = S_o + 1/m + n - 1$$



U	UNSATISFACTORY
U/M	MARGINALLY UNSATISFACTORY
M	MARGINAL
S/M	MARGINALLY SATISFACTORY
S	SATISFACTORY

S–RATING INTERCEPT (S_o) = 56 dB (A)
ZONE WIDTH (W) = 11 dB
SLOPE OF ZONE (m) = 1 RATING SCALE UNIT PER dB

Figure 4. Subjective ratings of noise in large berthing compartments (left axis) and percent of those compartments meeting each rating (right axis) as a function of A-weighted sound level. Data from eight Navy ships.

APPENDIX A: NOISE DATA FORM

NOISE DATA FORM #2

THE PURPOSE of this form is to find out whether or not the noise in this space affects work performance.

DATE ___/___/___ **SHIP:** ____________________

S# ____ **COMPARTMENT: NAME** ______________

NUMBER ___-___-___

YOUR RANK/RATE/TITLE ________ **WORK STATION/JOB NAME** ______________

Hearing: normal__ slight loss__ substantial loss__ trouble hearing speech__

1. (a) How long have you been working aboard ships at sea? ___ years
   (b) How much time have you spent at sea on this particular ship? ________
   (c) When at sea, how much time do you usually spend in this particular compartment? ___ hours per day.

2. This room now is (circle one):
   - quieter than normal cruising = 1
   - about as noisy as normal cruising = 2
   - noisier than normal cruising = 3

3. The noise in this room now is (circle one):
   - not bothersome = 1
   - slightly bothersome = 2
   - moderately bothersome = 3
   - quite bothersome = 4
   - very bothersome = 5

4. How often does the NOISE in this room INTERFERE with any of the USUAL ACTIVITIES in this room (working, talking, listening, reading, recreation, sleeping, etc.) during normal cruising?
   - occasionally = 1
   - frequently = 2
   - almost always = 3

5. (a) Would the NOISE in this room now INTERFERE with any of the USUAL ACTIVITIES in this room (working, talking, listening, reading, recreation, sleeping, etc.) (circle one):
   - YES
   - NO

   (b) If YES, what is the noise, and what activities does it interfere with?

   ____

   ____

6. CONTINUED ON OTHER SIDE . . . .

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APPENDIX B: A SUBJECTIVE RATING SCALE

Define a rating scale as follows:

Rating	Bothersomeness	Interference Complaints	Impact on important functions
S (satisfactory)	"Not bothersome"	Negligible	None
S/M (marginally satisfactory)	"Slightly bothersome"	Scattered	Slight
M (marginal)	"Moderately bothersome"	Trend beginning	Some probable
U/M (marginally unsatisfactory)	"Quite bothersome"	Definite pattern	Definite
U (unsatisfactory)	"Very bothersome"	Widespread	Severe

Note: This scale is a composite which the author found useful for general guidance in rating compartments. The individual measures would normally be treated separately, since they are not necessarily related to one another as shown here. In his subjective analysis, the author weighted interference reports much more heavily than bothersomeness reports.

APPENDIX C: COMPUTATION WORKSHEET AND SAMPLE GRAPH PAPER

Table C-1. Computation worksheet for figure C-1.

Satisfactory rating intercept (estimated) = S_o = ____ dB(A)

Zone width (estimated) = w = ____ dB

Slope (estimated) = m = ____ rating units/dB

$1/m$ = ____ dB/rating unit

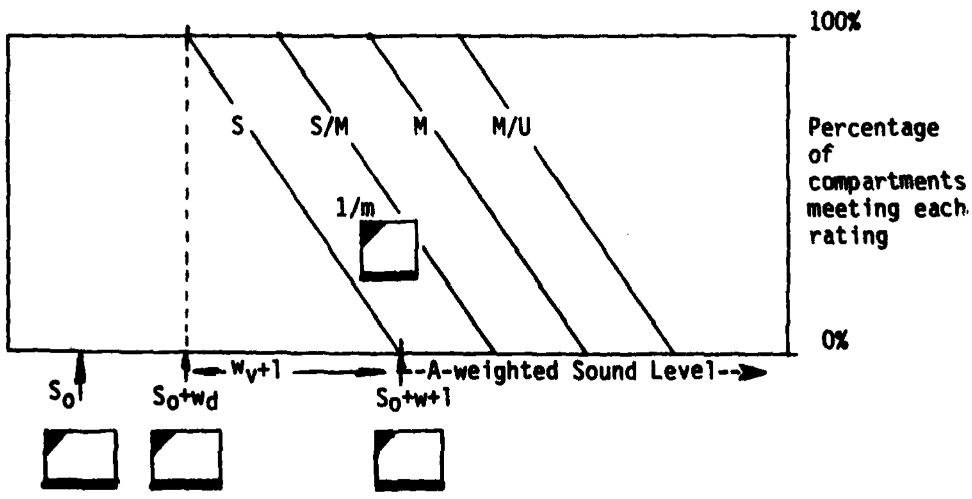
w due to discrete scale = $1/m - 1$ = (____ - 1) = w_d = ____ dB

____ + ____ = $S_o + w_d$ = ____ dB(A)

w due to variability = $w - w_d$ = (____ - ____) = w_v = ____ dB

$n = w_v+1 =$ ____

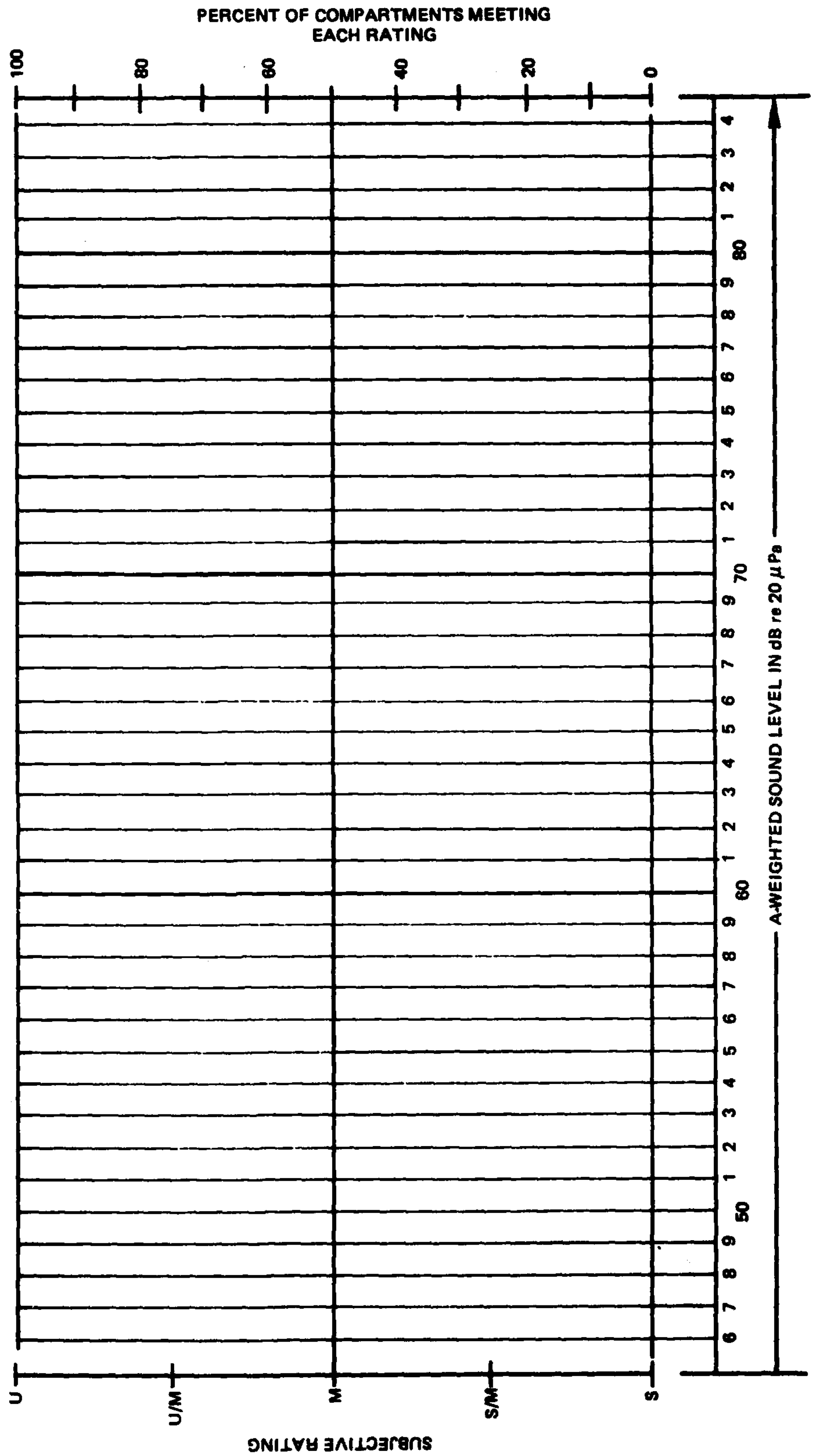
____ + ____ + 1 = S_o+w+1 = ____ dB(A)



Notes: Zone width (w) = width due to slope + width due to variability

$$= w_d + w_v = (1/m - 1) + (n - 1)$$
$$= 1/m + n - 2$$

$$S_o+w+1 = (S_o+w_d) + (w_v+1) = S_o + 1/m + n - 1$$


PERCENT OF COMPARTMENTS MEETING EACH RATING
100
80
60
40
20
0
U
U/M
M
S/M
S
SUBJECTIVE RATING
A-WEIGHTED SOUND LEVEL IN dB re 20 μPa
80
70
60
50

APPENDIX D: THEORY

INTRODUCTION

Several alternatives are available for summarizing the relationship between the subjective ratings and sound levels in figure 1. One might calculate and plot subjective rating distributions, as a function of sound level, directly from the measured data. This would not be very useful in this case, because the quantity of available data for each rating is very small and the distribution of sound levels actually measured is not at all uniform. The resulting distribution curves would therefore be very imprecise, even if the data were grouped into 5-dB wide sections, or if a cumulative distribution were used. And, it would be unlikely that a consistent relationship among the various rating curves would be obtained.

These difficulties can be overcome by first deriving, theoretically, the general form of a set of rating distribution curves, assuming an equal number of compartments at each sound level. These curves may then be constructed by using parameters estimated from a function fitted to all of the measured data. In this case, we use a linear approximation and 3 parameters.

SIMPLEST CASE

Figure D-1 illustrates an idealized case in which a single compartment is rated at each sound level by a single individual. At a level at or below 62 dB(A), the compartment is rated as satisfactory; at 63 dB(A), it is rated as marginally satisfactory; at 64 dB(A), marginal; at 65 dB(A), marginally unsatisfactory; and at or above 66 dB(A), unsatisfactory.

The satisfactory rating intercept (S_0) of a straight line drawn through the transition zone points represents a threshold above which the individual begins to be affected by the noise. In this case, it is 62 dB(A).

The slope (m) of the transition line indicates the sensitivity of the individual to noise, once the threshold level has been exceeded. In this case, since the slope is one rating unit per dB, the individual is changing his rating of the noise by one unit per dB increase in sound level, once a level of 62 dB(A) has been exceeded.

The width (w) of the transition zone we define to be zero in this case, because specifying any of the intermediate rating scores uniquely determines the sound level. The width is made up of two parts, which will be discussed below: a width due to the discrete nature of the rating scale (w_d), and a width due to variability (w_v). Here, we simply state that in this case w_d is zero, because the slope is not less than one rating unit per smallest resolvable unit of the sound level measurement; and w_v is zero by definition, because we assume there is no variability. With no variability, a similar graph would be expected for ideal data from a group of personnel rating a group of compartments. Of course, this zero variability condition does not occur in practice for a variety of reasons, including the presence of

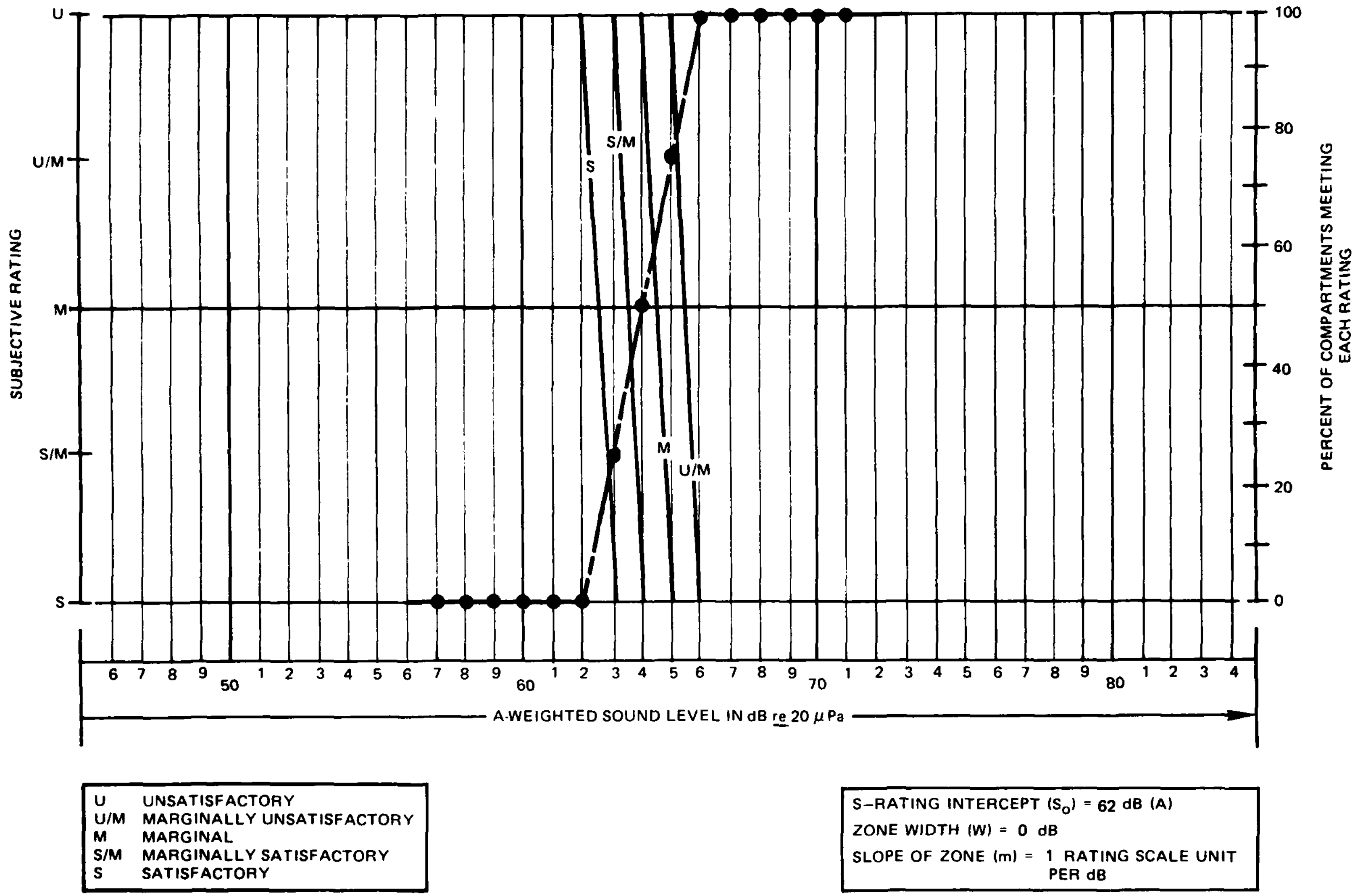


Figure D-1. Subjective ratings of noise in hypothetical compartments (left axis) and percent of those compartments meeting each rating (right axis) as a function of A-weighted sound level.

fluctuating or impulsive sounds and differences among noise spectra, room acoustics, measurement techniques, functions performed, and individuals.

The information above may be expressed by calculating and plotting the percentage of compartments meeting each rating, as a function of sound level. When this percentage is plotted, the result is four parallel straight lines sloping downward as in figure D-1. These lines have been labeled S, S/M, M, and U/M. To find the percentage of compartments which would meet a particular rating at a specified sound level from this graph, locate the sound level on the horizontal axis and follow a vertical line until it intersects the desired rating. Then, read the percentage of compartments which will meet this rating from the scale on the right. For example, the M-rating line shows that at or below a level of 64 dB(A), 100% of the compartments are rated as marginal or better; and that at or above a level of 65 dB(A), 0% are marginal or better.

TRANSITION ZONE WIDTH

The zone width (w) will not always be zero, even when there is no variability, because the rating scale is discrete. When the ratings are less sensitive to changes in sound level than in figure D-1 (i.e., when the slope (m) is less than 1 rating unit per dB), the rating remains at the same value for more than 1 dB before shifting to the next higher value. This increases the apparent width of the transition zone. This is illustrated in figure D-2, in which the zone width of 2 dB is due to the fact that the slope is 1/3 rather than 1. In practice, this width due to the discrete nature of the rating scale will probably be small (0 to 2 dB), and may be calculated from the expression:

$$w_d = 1/m - 1 \; . \qquad (1)$$

In this case, note that:

the highest sound level for which all compartments are rated satisfactory $= S_0 + w_d$ (2)

$= 62 + 2 = 64$ dB(A) .

In interpreting data, we assume the slope has a value between 0 and 4 (the number of intervals in the rating scale). If the slope is less than zero, it implies that noise improves the rating. This might be the case, for example, if the steady noise which was measured served to mask transient noises which were not considered in the analysis. Of course, if the slope is zero, it simply means that changing the level of the noise does not affect the ratings. If the apparent slope is greater than 4, approximating it as equal to 4 would be consistent with the precision of the sound level measurements.

In real data, of course, variability due to the many variable factors listed above also causes the transition zone to broaden. We may approximate this effect by assuming the subjective rating scores assigned to the various compartments are spread uniformly over a range of sound levels. For illustration, let us assume that the total number of rating scores can be divided into n = 6 equal-sensitivity groups, and that within each such group the rating scores are equal to each other for any given sound level and change together as sound level increases.

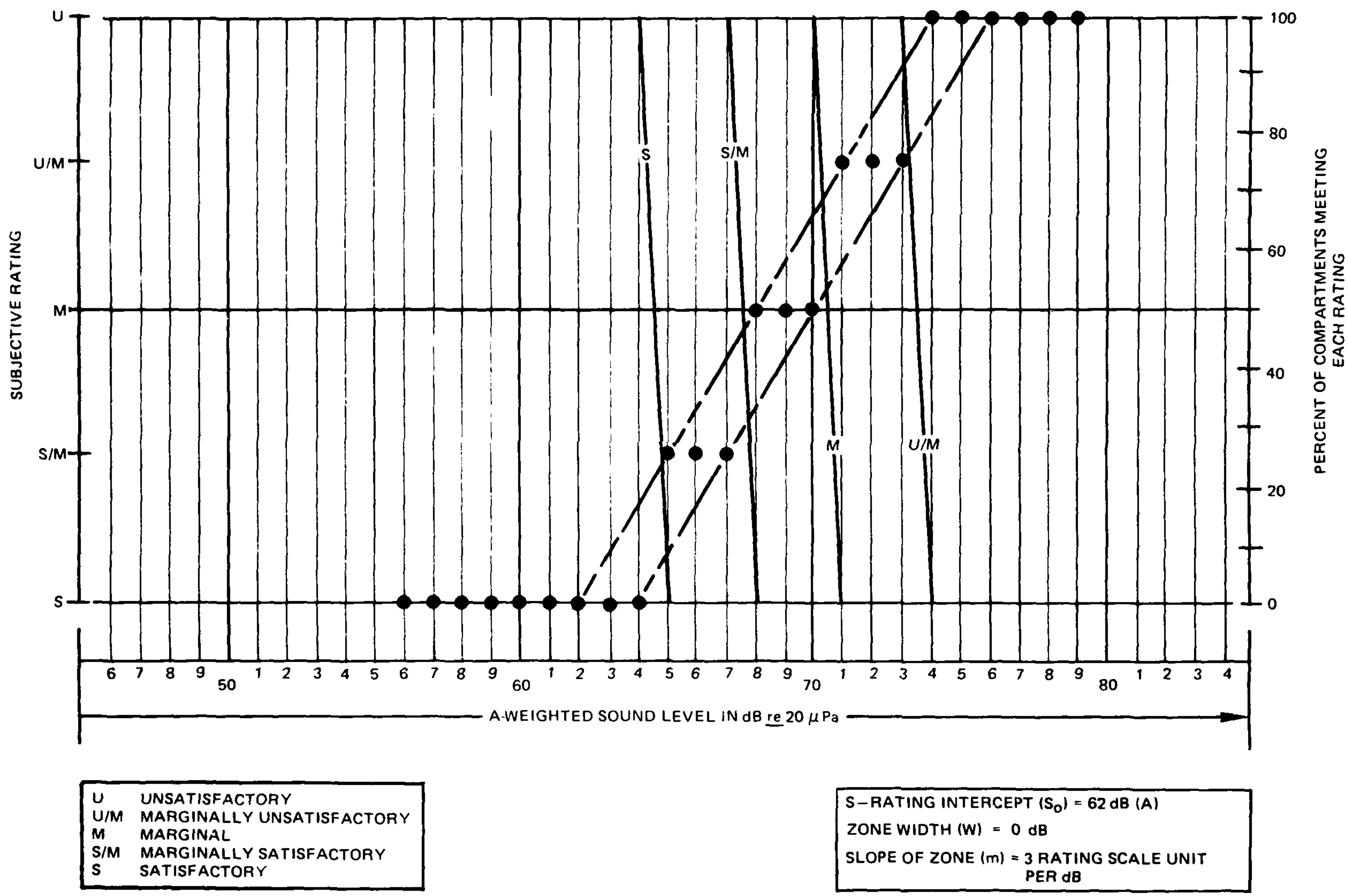


Figure D-2. Subjective ratings of noise in hypothetical compartments (left axis) and percent of those compartments meeting each rating (right axis) as a function of A-weighted sound level.

This is illustrated in table D-1 and figure D-3, for which the slope is one. We assume all ratings are satisfactory at or below S_0 (62 dB(A)). When the sound level exceeds S_0 by 1/m (1 dB), 1/n = 1/6 of the ratings are marginally satisfactory. When the level increases by another 1/m, these ratings change to marginal, and an additional group of 1/n ratings changes from satisfactory to marginally satisfactory. This progression continues in linear fashion through the transition zone until all of the ratings are unsatisfactory.

The width of the transition zone due to this variability is:

$$w_v = n - 1 \tag{3}$$

The total width of the transition zone is therefore:

$$w = w_d + w_v \tag{4}$$

$$= (1/m - 1) + (n - 1)$$

$$= 1/m + n - 2 \tag{5}$$

PERCENTAGE OF SUBJECTIVE RATINGS MEETING SPECIFIED RATING

For any given sound level, we can now calculate the percentage of subjective ratings better than or equal to any given rating. In figure D-3, for example, 5/6 of the spaces with a sound level of 65 dB(A) are rated as marginal or better, 4/6 of those with a sound level of 66 dB(A) are marginal or better, and so on.

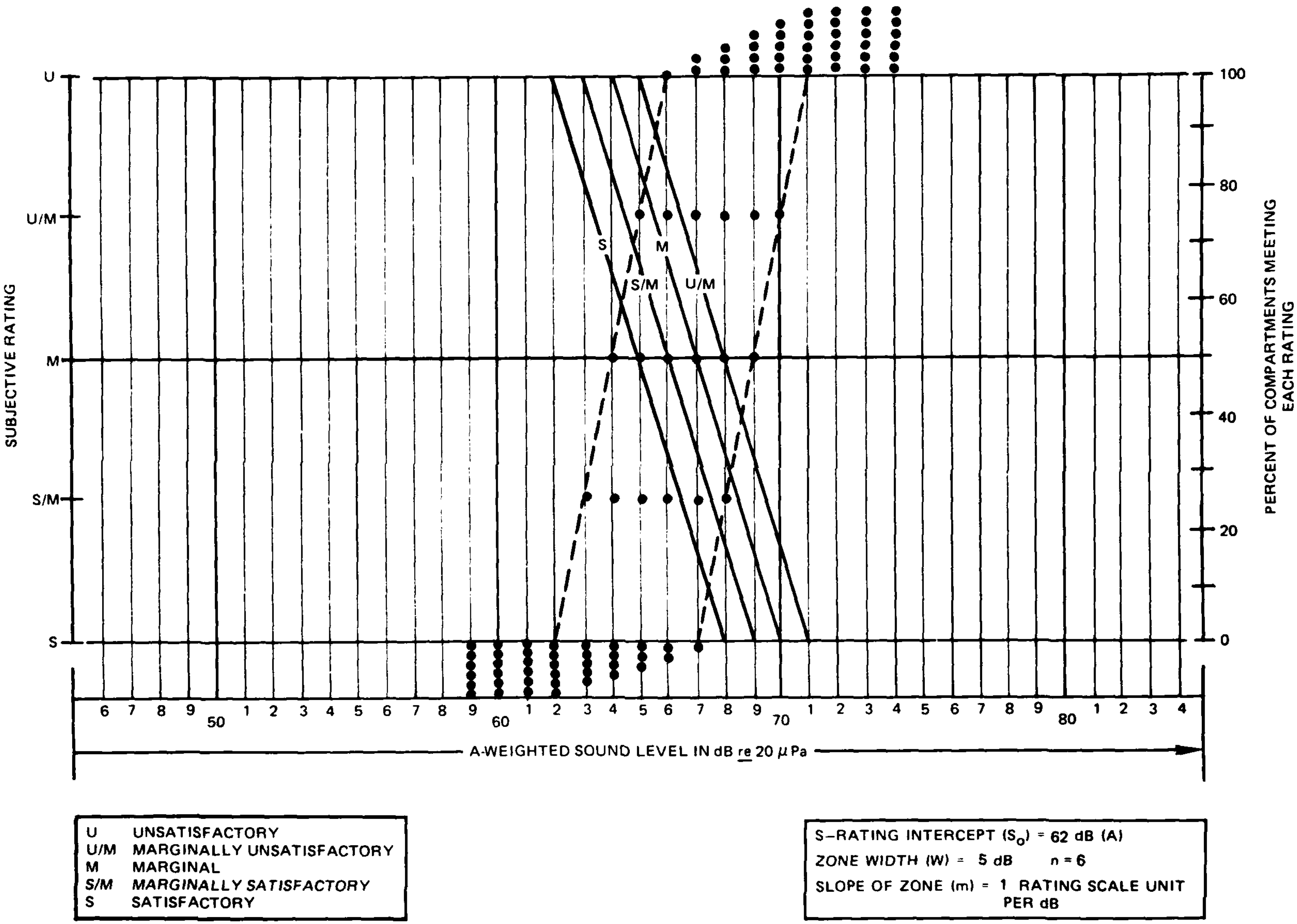


Figure D-3. Subjective ratings of noise in hypothetical shipboard compartments (left axis) and percent of those compartments meeting each rating (right axis) as a function of A-weighted sound level.

Table D-1. Computation worksheet for figure D-3.

Satisfactory rating intercept (estimated) = S_o = 62 dB(A)

Zone width (estimated) = w = 5 dB

Slope (estimated) = m = 1 rating units/dB

$1/m$ = 1 dB/rating unit

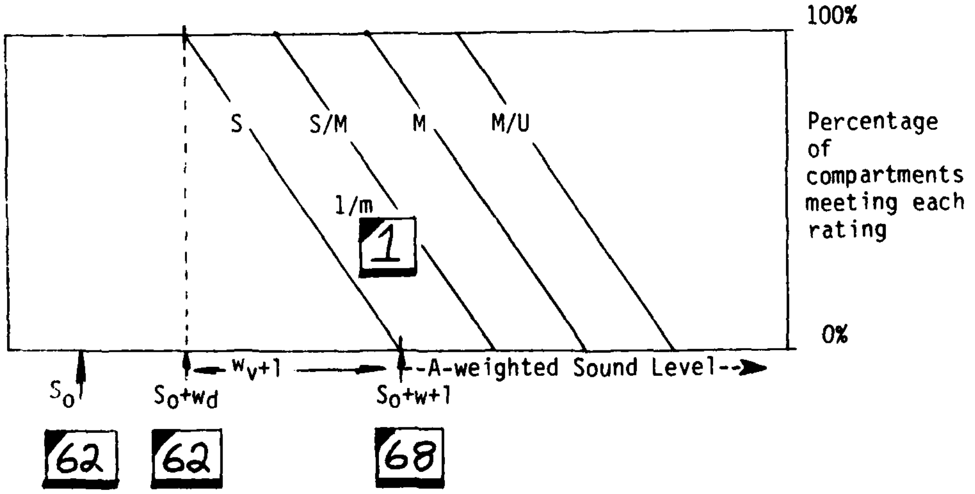
w due to discrete scale = $1/m - 1$ = (1 - 1) = w_d = 0 dB

62 + 0 = $S_o + w_d$ = 62 dB(A)

w due to variability = $w - w_d$ = (5 - 0) = w_v = 5 dB

$n = w_v + 1$ = 6

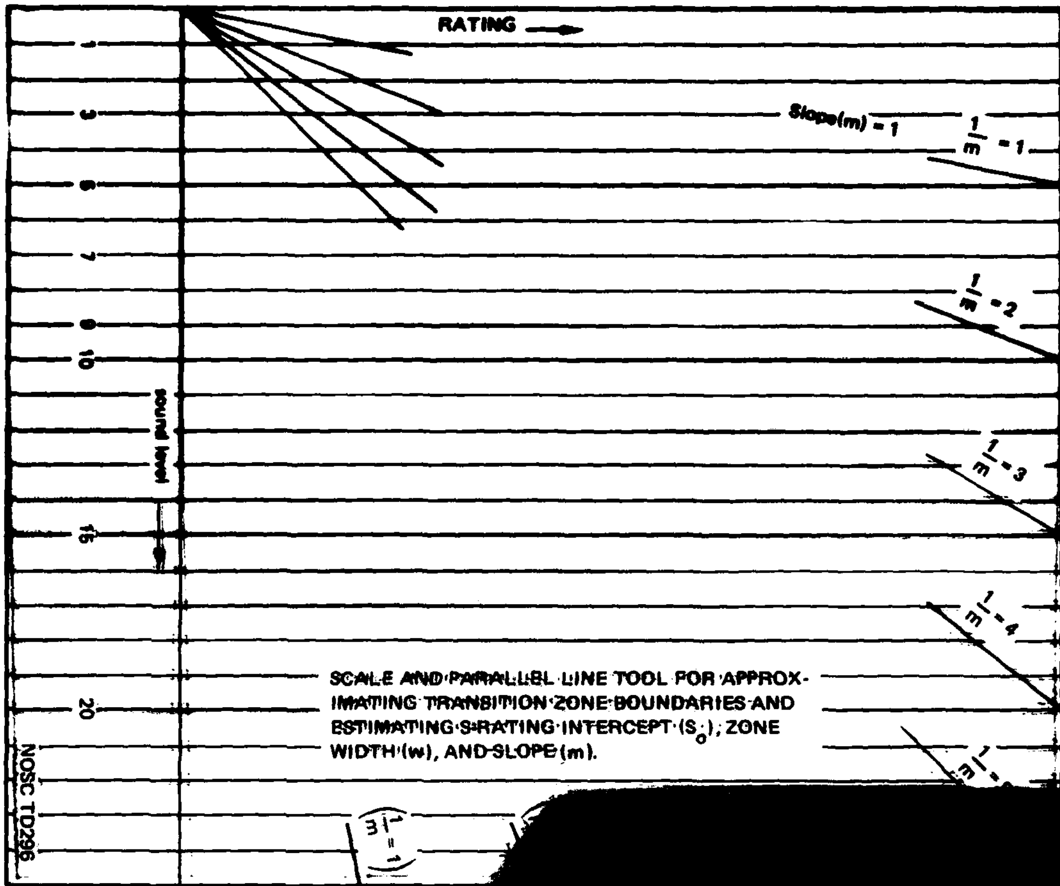
62 + 5 + 1 = $S_o + w + 1$ = 68 dB(A)



Notes: Zone width (w) = width due to slope + width due to variability

$$= w_d + w_v = (1/m - 1) + (n - 1)$$
$$= 1/m + n - 2$$

$$S_o + w + 1 = (S_o + w_d) + (w_v + 1) = S_o + 1/m + n - 1$$



Aid enclosed for fitting parallel lines to data and determining zone width and slope. Practice the method before using the aid.

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